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"It Seems Like I'm Doing Something More Important"—An Interpretative Phenomenological Analysis of the Transformative Impact of Research Experiences for STEM Students with ADHD

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Abstract: Recent studies have suggested a link between attention deficit hyperactivity disorder (ADHD) and increased creativity and ingenuity. Clinical work suggests that individuals with ADHD generally gravitate toward exploratory rather than exploitative thinking. Yet, these theories have not been tested in the field. This paper is a case study of a transformative undergraduate summer research program that allows engineering students with ADHD to spend 10 weeks in engineering labs at a research-intensive (R1) university. The program intends to show that students with ADHD can excel in engineering and STEM fields when placed in research environments that align with their natural cognitive processes and preferences. Using an interpretative phenomenological analysis (IPA) on post-program participant interviews, this paper suggests that engineering students with ADHD perceive that they learn more effectively when given the opportunity to explore academic material via hands-on research. The traditional structure of STEM education, with its focus on lectures and rigid curricula, causes significant harm to these students, leading to struggles, anxiety, and even thoughts of dropping out. In contrast, the research environment appears to foster creativity and motivation in students with ADHD, as it allows for exploration, provides real-world problem-solving opportunities, and offers tangible, hands-on experiences. This paper highlights the need for a paradigm shift in engineering pedagogy to better engage with and retain this neurodiverse student population and fully harness their creative potential.

Keywords: ADHD; engineering education; interpretative phenomenological analysis; self-determination theory; strength-based learning

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1. Introduction

The field of engineering has long considered creativity to be an essential skill for students and graduates to possess [1–4]. The National Academy of Engineering (NAE) identified nearly two decades ago that creativity is necessary for solving the complex, often interdisciplinary, challenges facing the modern engineering workforce [4]. While research highlights that divergent thinking is a fundamental component of creativity [1,5], there remains a disconnect between promoting creative problem solving and the structure of engineering curricula, where creative solutions and innovation do not necessarily improve academic performance [6].

While STEM education often resists creativity, cultivating more creatively minded students remains an important goal. Engaging and retaining neurodiverse students, including those with attention deficit hyperactivity disorder (ADHD), could contribute to a more imaginative engineering workforce capable of addressing complex, interconnected issues [7–10]. White and Shah first proposed in 2006 that ADHD increases creativity [11], a theory reinforced by their later research [12,13] and supported by additional studies [14,15]. Initially, this suggestion was met with doubt, and it contributed to the viewpoint that ADHD should be treated and managed rather than leveraged as a potential strength [16–18]. Over time, however, the literature began to recognize the potential benefits of ADHD in fostering creativity and innovative thinking, despite the condition's persistent stigmatization [19–22].

Two popular explanations for the link between ADHD and increased creativity are as follows: (1) a wider attention filter allows for more information processing with less specificity; (2) a preference for information exploration. On the former, Abraham et al. (2006) suggest that "[t]he wider one's attentional focus then, the more the number of elements activated in one's attentional stream and with it, the enhanced possibility of arriving at a more unique blending of elements and consequently more original ideas." This broader focus "confers a selective advantage on specific facets of creative thinking that call for disregarding an immediate context" [23]. Later studies suggest these effects persist into adulthood, favoring divergent and novel thinking [11,24]. These skills greatly benefit engineering students [6,10,25].

The cognitive preference theory suggests that those with ADHD favor problem solving via exploration over exploitation [26,27]. Exploration involves searching for new solutions, while exploitation relies on previously known information [28]. One explanation proposes those with ADHD are less immediately reward driven and, without external incentives, are willing to explore unknowns for potential gain [26]. Van den Driessche et al. (2019) connect this theory to the divergent thinking and creativity thesis of White and Shah, suggesting that increased creativity, rather than a lack of inhibitory control, is responsible for this exploratory preference. This preference could result in higher performance in STEM fields, particularly if the educational environment aligns with it [7,25,29].

Despite this potential link between ADHD and creativity, the engineering pipeline has yet to leverage the former to benefit the latter. Students with ADHD only make up 3% of engineering undergraduates, despite comprising 25% of the general student population [8,30–34]. It is difficult to understand the exact number of students who might be considered neurodiverse in graduate programs. Reported statistics place the number of neurodiverse students in graduate STEM programs between 1 and 3% [35–37]. However, we suggest that any reported number may not provide an accurate count since many neurodiverse graduate students choose to not disclose their diagnosis or seek formal support from their universities [38].

This discrepancy is likely in part due to the limited opportunities for students to incorporate their creativity and divergent thinking skills within traditional engineering curricula. The "standard" undergraduate engineering curriculum follows a systematic and sequential structure intended to shape students into adept engineers. In the first year, students take basic courses in physics, chemistry, and math, which lay the groundwork for more complex engineering concepts. However, their modality is typically textbook-focused, leaving little room for novel reasoning. During the second year, the curriculum deepens with discipline-focused courses, like statics and circuits. Despite increased complexity, instruction still adheres rigidly to standard approaches to problem solving, potentially stifling creative exploration. In junior year, coursework is more applied, with lab courses often integrating strictly formulated experiments and data collection methods. These courses enable students to engage with practical elements of engineering. However, the exact nature of the experiments discourages creativity or out-of-the-box thinking. In senior year, even as the emphasis shifts to design courses and capstone projects, the prescriptive nature remains. Although, in these courses, students are implicitly encouraged to use creative problem solving, rigid guidelines can limit their space for innovation; in addition, this off-the-cuff encouragement comes too late in the curriculum, and without enough training for them to expand beyond the problem-solving skills they learned in previous years. The end result is, as Kazerounian and Foley note, "[r]egurgitating known solutions has become the norm without the balance of allowing students to keep that sense of wonder" [39].

Throughout the progression of the undergraduate engineering curriculum, although students acquire robust theoretical and practical knowledge, pedagogical inflexibility can curtail their ability to approach problems with creativity and original thinking. Often, undergraduate research experiences (UREs) are not a formal part of the engineering curriculum. As Faber et al. (2020) note, "the most recognized type of URE is the apprentice-style experience in which an undergraduate student works in a faculty member's research group; however, other types [. . .] include capstone experiences, internships or co-ops, course-based undergraduate research experiences (CUREs), project-based programs, and community-based research" [40]. As they further note, the self-selecting and competitive nature of UREs limits how applicable these research experiences can be to all STEM students [40].

As such, this present study intends to explore the connection between students with ADHD, their innate creativity, and the promise of the research environment as a logical approach to engage and retain this underserved population in STEM fields. Few substantial qualitative tests have explored creativity and ADHD, with most focusing on mitigating deficiencies rather than understanding individual strengths [41]. In this paper, we employ interpretative phenomenological analysis (IPA) to address two main research questions: (1) what is the association between ADHD and enhanced creativity in the context of engineering education, and (2) what are the lived experiences of individuals with ADHD in such educational settings?

Plucker et al. (2004) define creativity as "the interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context" [42]. Since this study engages with increased creativity within individuals with ADHD, we are particularly interested in the potential of divergent thinking to contribute to innovation in engineering contexts. Divergent thinking may be broadly defined as the ability to produce multiple solutions to open-ended problems [43]. Within the context of open-ended engineering problems, divergent thinking may be demonstrated with the number of solutions generated (fluency), the novelty of the solutions (originality), the variety of approaches to the solution or types of solutions (flexibility), and the level of detail related to the solutions (elaboration) [44]. As White and Shah (2016) suggest, "higher levels of divergent thinking and creative achievement among individuals known to have lower inhibitory control" [13].

In this study, we ground our theoretical foundation in the strength-based approach and Self-Determination Theory (SDT) to explore the unique experiences and strengths of individuals with ADHD in engineering education. The strength-based approach emphasizes the identification and cultivation of individuals' strengths rather than focusing solely on weaknesses or deficits [45,46]. In parallel, SDT posits that individuals are inherently motivated to grow and achieve psychological well-being when their basic psychological needs for autonomy, competence, and relatedness are satisfied [47,48]. As Kazerounian and Foley (2007) note [39], prior research suggests that increases in student self-determination may lead to increased creativity within the learning environment [49]. By integrating these frameworks, we aim to understand how ADHD may be associated with enhanced creativity in the context of engineering education and, thus, how to better support the educational experiences of individuals with ADHD.

We employ IPA to uncover the lived experiences and perspectives of individuals with ADHD in engineering education, using this information to inform pedagogical practices that better align with their unique strengths and needs. IPA was selected for this study due to its emphasis on exploring lived experiences and individual cases, which aligns well with both the strength-based approach and SDT [46–48]. This methodology allows for rich, in-depth insights into the diverse range of strengths and challenges faced by students with ADHD in engineering education, providing a comprehensive understanding of their experiences from a growth-oriented and holistic perspective.

Participants in this study were selected from an NSF-funded Research Experiences for Undergraduates (REU) Site, a specialized, 10-week summer research program at an R1 university. This program encouraged students with ADHD to pursue academic research and graduate education, providing an opportunity to understand their experiences in engineering education. This study aimed to understand if participants felt they could learn more easily in the exploratory research environment compared to standard educational modes. Interview data suggest a potential link between ADHD, creativity, and the perception of increased learning via the open-ended research process. Broadly speaking, participants found the research environment highly motivating and better aligned with their learning preferences than the traditional classroom.

However, the pain and frustration detailed by participants regarding the conventional STEM education system are concerning. A consistent narrative of struggle, anxiety over coursework, excessive burnout, and thoughts of dropping out emerged. The findings suggest that the engineering education system is failing students who are well-suited to push the field forward. The standardization of STEM curricula rejects promising young talent due to their non-conformity despite the field's need for ingenuity [4]. The potential implications of this study for engineering education, policy, and practice are significant, as it addresses the importance of promoting neurodiversity and creativity within the engineering workforce. By better understanding the experiences and cognitive strengths of students with ADHD in engineering education, we can develop more inclusive teaching strategies and learning environments that cater to their unique needs. This may not only improve the educational experiences and outcomes for these students but may also contribute to a more diverse and innovative engineering workforce.

2. Methodology

2.1. Interpretative Phenomenological Analysis

This IRB-approved study utilizes Interpretative Phenomenological Analysis (IPA) as the mode of analysis. IPA gathers data via interviews with a small group of subjects, even as small as an individual subject [49]. Its goal is to thoroughly investigate the participant's lived experience on the topic being studied [50]. This approach is phenomenological, as it seeks to capture the individual's personal perception of an object or event rather than attempting to objectively describe it [51]. IPA places emphasis on emotion and cognition, making it a suitable method for understanding the perspectives of participants. Through this methodology, we can gain insight into what motivated these students to pursue research and why traditional curricula impede their academic progress. To address the concerns related to the specific steps taken during the analysis and derivation of global themes, we provide a more detailed description of the analysis process below.

2.2. Self-Determination Theory

The Self-Determination Theory is a psychological framework that focuses on understanding human motivation, personal growth, and well-being. Developed by Deci and Ryan, SDT emphasizes the importance of satisfying three basic psychological needs for individuals to thrive: autonomy, competence, and relatedness [46]. Autonomy refers to the desire for self-determination and the ability to make choices, while competence involves the desire to feel effective in one's actions and to experience mastery. Relatedness encompasses the desire to feel connected to others, belong to a community, and receive care from others [52]. SDT has been used by several researchers in educational practice [53–56].

In this paper, SDT guides the exploration of students with ADHD's experiences in engineering education, examining how traditional and research-based learning environments support/hinder the satisfaction of these basic needs. Through the SDT lens, this study aims to identify ways to enhance motivation, engagement, and overall well-being of students with ADHD. The insights gained from this analysis can inform the development of pedagogical practices and educational policies that better cater to the unique strengths and needs of these students, ultimately contributing to a more diverse and innovative engineering workforce. This approach aligns with the strength-based perspective, recognizing the potential of students with ADHD to excel in their education when provided with the appropriate support and environment [45,46].

2.3. The Strength-Based Approach to Undergraduate Research

This REU Site is part of a wider paradigm shift in engineering education, employing the strength-based model of instruction [7,10,25,45]. A strength-based approach frames the natural variations in human cognition as assets that enrich society and aid in tackling complex problems via nontraditional approaches. Grounded in the framework of positive psychology, this approach identifies, nurtures, and capitalizes on individual assets [45]. In the context of education, students are encouraged to expand their awareness of and implement strategies to leverage their strengths [55]. This approach is intended to enhance student engagement by activating strengths, which may be particularly important for neurodiverse students who struggle with motivation and engagement [45,57]. This lens has been a powerful strategy for harnessing the diverse abilities of students aspiring to join the STEM workforce [56].

The Site combined a 10-week, traditional REU research experience with seminars, brainstorming sessions, and workshops addressing the needs and challenges of neurodiverse participants. The research experience allowed students to form an in-depth understanding of a critical research challenge related to their academic major(s). The environment, which combined the open-endedness of research with the interpersonal bonding of non-research activities, facilitated deeper engagement, leading to a better understanding of engineering and enabling them to generate novel solutions that advance the field.

Research topics ranged widely, from assessing the safety of bridge structures to creating reliable random generators for encryption tasks, highlighting the program's broad scope. Importantly, research projects were outside of the standard curriculum. Students participated in research initiatives under the guidance of faculty mentors, sometimes also collaborating with graduate student mentors to further their understanding of research processes. Each faculty mentor had their individually managed projects, either funded or unfunded. Participant contributions within these projects varied, some contributing to larger research goals via data collection and analysis, and others were carved out of broader activities and tailored to the individual student's learning. Frequency of contact between students and their graduate mentors/faculty varied depending on each faculty's lab management style. Further details can be found at the link provided in the funding statement below.

2.4. Study Participants

Participants for this study were selected from those attending the REU Site. For the selection of participants in the REU Site, the process was specifically tailored to attract and include students who identified as neurodivergent. The Site was listed on the NSF directory, and the PIs actively promoted the opportunity to the target audience. Students interested in participating were asked to complete an application, which included uploading their transcripts and personal statements, as well as self-reporting their neurodiversity status. This approach ensured that the REU Site was composed of a group of students who openly acknowledged their neurodivergent identities, fostering an inclusive and supportive research environment. REU students all identified as having ADHD though no medical diagnosis was required. Requiring one would bias against students who could not afford formal evaluation or those for whom cultural and/or family stigma would disincentivize diagnosis.

All 10 students from the final funding year of the Site were invited to participate in this study, which took place near the conclusion of the REU Site. Participant demographics are summarized in Table 1 below. Two of the students initially accepted the invitation to interview but withdrew prior to completing the interview process. All participants were current undergraduate students in STEM programs across the country for whom this Site was their first experience with undergraduate research. Their majors included Electrical Engineering (3), Mechanical Engineering (2), Computer Science Engineering (3), Chemical Engineering (1), and Physics (1). Two participants were dual majors in Math and Philosophy, respectively. Half of the participants received formal academic accommodation at their home institution. The participants are given the following aliases: Bridget, Mark, Daniel, Natasha, Colin, Pamela, Tom, and Julian. To avoid undue influence, participants were contacted for interviews by a professional research staff member who had no relation to the Site and no responsibility over the participants.

Table 1. Summary of demographic information (N = 10).

Sex	**N (%)**
Female	4 (40%)
Male	6 (60%)
Race/Ethnicity	
Hispanic or Latinx	1 (10%)
White	9 (90%)
Highest Grade Completed	
Freshman	1 (10%)
Sophomore	2 (20%)
Junior	7 (70%)
Major (Field of Study)	
Chemical Engineering	1 (10%)
Computer Science Engineering	3 (30%)
Electrical Engineering	3 (30%)
Mechanical Engineering	2 (20%)
Physics	1 (10%)
Dual major reported (Math, Philosophy)	2 (20%)

Note: Two participants did not complete the interview process.

2.5. Data Collection

Individual interviews were semi-structured around open-ended questions to encourage detailed narratives [51,58]. Interviews were scheduled for two hours to ensure adequate time to explore ideas. Participants were asked to reflect on two discrete phases of their academic journey: their STEM education prior to coming to the REU Site and their experience within a research lab while in the program. Participants were encouraged to compare the two environments. The question bank can be found in Appendix A. The interviewer was a doctoral candidate in psychology. Interviews were audiotaped and transcribed by one co-author who was uninvolved with participants during the Site. The transcriber redacted identifying information prior to making data available to fellow co-authors.

Interviews were conducted in a private room within the university away from high-traffic areas to reduce external distractions [57]. Interviews took place near the conclusion of the Site in 2019. Participants were given written information about this study and asked for their informed consent. Audio recording began when participants indicated they were ready.

2.6. Analysis

The IPA method was employed to synthesize interview data, following a structured, iterative process [51,59,60]. The analyst first listened to anonymized interview audio multiple times to develop familiarity with the material, capturing the nuances of tone and emotion that might be lost in the transcripts. Next, an initial coding of local themes within each text was conducted during a thorough reading of the transcripts, with cross-participant themes not considered at this stage. In subsequent readings, the analyst identified and coded broader themes present across multiple or all transcripts, looking for patterns, similarities, and differences in the participants' experiences and perceptions.

Utilizing ATLAS.ti, a qualitative research software, the analyst generated "global themes" by combining and refining the broader themes to better represent the participants' experiences [59]. This process involved making connections between themes, considering the relationships among them, and interpreting and reinterpreting the text through multiple readings [50,51]. To enhance the reliability and rigor of our analysis, we utilized inter-coder reliability checks and triangulation. Two independent researchers coded the interview transcripts, and their coding schemes were compared to assess consistency and agreement. Discrepancies were discussed and resolved via consensus, minimizing potential biases, and ensuring the reliability of the coding process.

The primary analyst, a social scientist with extensive knowledge of qualitative research methods, had no direct interaction with REU participants during or after their involvement in this study. However, they discussed the global themes with co-authors who had direct interaction with the participants during the program to ensure their understanding was consistent. Co-authors provided feedback on the themes, and the primary analyst revised and refined themes accordingly. Triangulation was employed by cross-verifying the data from different participants and comparing their experiences and perspectives to identify common themes and patterns, providing a comprehensive understanding of the phenomenon and minimizing potential bias from relying solely on a single data source. After several rounds of validation and refinement, the final set of global themes was established and used to structure the findings and discussion sections of the paper. This collaborative effort enhances rigor and reduces potential bias.

2.7. Reflexivity

Performing IPA requires a recognition that, because of the intimate process of interpretation, the researcher's perspective will inevitably affect analysis [61,62]. We acknowledge at the outset personal factors which may impact our conclusions [63]. Our influences include the following: multiple co-authors have ADHD diagnoses; multiple co-authors are faculty within a School of Engineering; previous research by co-authors related to neurodiversity; co-authors have experience teaching and mentoring undergraduate students. These influences help build rapport with participants and thus produce a more robust analytical product. Co-authors discussed potential influences prior to analysis to encourage awareness of preconceptions and potential impacts.

3. Results

This study simultaneously highlights how students with ADHD may leverage their creativity (divergent thinking) for success within the research environment and the harms inflicted on this population by the traditional structure of STEM education. Consistently, participants voice difficulties with traditional education and felt they understood engineering fundamentals better and developed new skills after their time in our research environment. Three global themes emerged in our analysis, each of which points to this duality: (1) the traditional STEM education structure causes demonstrable harm for students with ADHD, (2) exploration drives engagement, and (3) solving real-world problems and tangibility increases motivation. The contrast between the traditional engineering education environment and the research environment was apparent in all of these themes, particularly in relation to the ways in which the nature of the environment encourages or limits the creative exploration of complex problems. Combined, these themes suggest the transformative nature of matching student strengths with their environment rather than the one-size-fits-all approach currently in STEM education.

3.1. Theme 1: The Demonstrable Harms of Conventional Education

To determine the effect of this REU experience on students with ADHD, the interviewer asked participants to compare their learning prior to the program in conventional STEM education settings against the summer research environment. Upon reflecting on their experiences to that point, a stark picture emerged of students suffering from an educational mode antithetical to how they process and utilize information. We find it necessary to underscore at the outset the silent suffering of students with ADHD to outline how transformative the REU experience was through later themes. Harms range from being overwhelmed by the core processes of conventional education to significant self-doubt and considering leaving higher education entirely.

When asked about the impact of ADHD on their education, participants voiced an inability to conform to the expectations of lecture-style learning, whether participants have formal accommodations at their home institution or not. This suggests that traditional accommodations (note takers, extra time on tests, etc.), as suggested by Allsopp et al., fail to address the underlying issue of the most popular modes of education prioritizing a style of learning to which students with ADHD struggle with adapting [64]. This can be seen in the following quote from Julian (n.b. brackets indicate editorial modification to the original quote for brevity and/or grammatical clarity; any non-bracketed ellipses are retained from the original transcript):

> *[Y]ou need to be able to listen in lecture, and also, like, take notes, um, and if you're not [...] perfectly up to date with the material, and you go to the next class, then...it will not really make sense [...T]here's been a lot of times where I just kind of ignore a class for a couple days because I'm working on something else, and then the class that I ignored gets even harder because I ignored it [...] And then it just keeps going like that, and, like, uh, I really don't take notes, typically, because I, like, stop paying attention if I do take notes. [...] I'm thinking about what I'm writing [...] I'm listening, but I'm just, like, regurgitating it onto the paper... So, I've found it more useful to not take notes. (Julian)*

Expecting students to split their focus between listening and writing notes sets those with ADHD for failure. Julian's compromise of listening but not writing solves the short-term problem but presents no means to recall specific information when studying. This overlaps with the conclusion of Reaser et al., that students with ADHD struggle significantly with concentration and information processing in the school environment [65].

Similarly, under traditional engineering curricula, participants expressed a tendency to procrastinate on coursework outside the classroom. Colin notes how the lack of satisfaction in classwork and the resultant demotivation can quickly spiral as students with ADHD find it increasingly difficult to bring themselves back to a task once they have lost incentive. "I was doing very good at the beginning of the semester...I was on top of everything, and [then] I sort of let everything slip, and just once it was out of my mind, it stayed out of my mind." Again, this process falls in line with the suggestions of Van den Driessche et al., that conventional modes of education would fail to engage students with ADHD and lead to a cycle of demotivation [27].

In isolation, these issues participants found when the education system conflicted with their ADHD may seem minor. However, Daniel shows how quickly these cycles and the consistent feeling of not fitting the mold of an engineering student can lead to crisis. When asked about how their ADHD influenced their educational experience, Daniel connected their mental-health-related challenges to the rigidity of the educational environment:

> *At first it was really bad. I almost dropped out of college [...] I was already psychologically going downhill, but I just, having ADHD, like, there would be days where I'd be studying 10 h for chemistry 101, which is, like, such an easy course, but like, just, the things they want us to do are so—it's you have to complete this, and you have to do it this way. And, like, figuring out what [instructors] wanted me to do is always really difficult. And it just kept progressing worse and worse and I ended up going to a hospital for a week and being out of school for a while. I was considering dropping out of school, so, I think ADHD had a big part in my experience, 'cause I struggled a lot more in classes than other people did.*

For Daniel, "this program is what is going to decide for me, like, my further engineering experience... if I'm going to continue in school, if I'm going to drop out, take time off, [or] try a different major." This experience is stark, but it is not abnormal for students with ADHD in STEM. If 25% of the general population has ADHD, but only 3% are engineering undergraduate students [8,30,33,34], then Daniel is not unique; Daniel is the outlier who stayed long enough to tell their story rather than drop out. When asked "do you feel that having ADHD confers any advantages for your success in your engineering program", Daniel's response shows a new understanding of how their ability to come up with multiple solutions to engineering problems (divergent thinking) may be an asset in engineering, given the right environment:

> *"I didn't until I came here... Now that I understand, like, I'm really creative, like, let me just try and figure out another way to be able to complete these processes... like, now that I'm aware, of... the way that I kind of tick a little bit better. Like, naturally I'm better at design courses, and, um, and lab courses... at least, like, now I, after going here I've learned more that, just because I can kind of look at everyone's ideas, and like figure out, like, all the possibilities that can happen, or like, try and come up with, like, ten ideas..."*

Our results suggest a throughline of harms felt by students both in- and outside the classroom, which contribute to feelings of inadequacy and are not mitigated by seeking accommodations. Participants directly linked these feelings to their ADHD, and it can lead them to determine that the best option is to leave education.

In the context of SDT, traditional engineering education often fails to satisfy the basic psychological needs of autonomy, competence, and relatedness for students with ADHD. Conventional education methods, such as lecture-based learning and prescribed curricula, do not provide students with ADHD the flexibility and freedom to explore their interests and develop creative problem-solving strategies in a way that aligns with their cognitive strengths [44,56]. This lack of autonomy can lead to decreased motivation and engagement, ultimately hindering their academic performance and well-being.

Furthermore, the strength-based approach emphasizes the importance of identifying and cultivating individual strengths rather than focusing solely on weaknesses and deficits. As demonstrated by Daniel's quote above, traditional engineering education often does not provide opportunities for students with ADHD to leverage their strengths, such as creativity and divergent thinking. Again, originality is a core component of the standard definition of creativity [66]; as students with ADHD are more novel, divergent thinkers than the general student population [13], the constraints imposed by traditional engineering curricula curtail students' abilities to maximize their strengths.

By failing to accommodate the unique learning needs of these students and prioritizing their strengths, the traditional engineering education system contributes to the demonstrable harm experienced by students with ADHD. This aligns with the findings of our study, which revealed the negative impact of conventional engineering education on students with ADHD.

3.2. Theme 2: Enhancing Engagement by Embracing Exploration

For many participants, the REU Site offered their first exposure to academic research, allowing them to engage in exploratory research and flourish in a manner that supports both clinical theories [13,27]and the expectations of engineering educators questioning the wisdom of a one-size-fits-all paradigm [25,29]. This alignment of educational mode with the cognitive methods of this community allowed students with ADHD to satisfy their basic psychological needs for autonomy, competence, and relatedness, as described via SDT.

The exploratory nature of research aligns well with the ADHD mindset; Taylor and Vestergaard (2022) connect exploration to both divergent thinking and diffuse attention, pointing toward research that found a shared mechanism between explorative search and high abilities in divergent thinking [28,67]. The research environment also provides students with a sense of autonomy, as they can pursue their interests and develop multiple problem-solving strategies rather than following a prescribed path. Boot et al., tied motivation with competition for those with ADHD, suggesting "people with ADHD may excel in specific creative tasks that match their preferences and abilities" [68]. Pamela describes how the research experience provides an environment in which they experienced the freedom to use divergent thinking for creative problem solving while noting the absence of this creative freedom within the traditional education environment:

Like, you research, you're trying to figure out a certain problem, and so you read a bunch of papers related to it, and you try to make your own solution to a specific problem, but in order to solve that problem, no one else knows the answer to the problem. That's why you're solving it. There are... there could be multiple solutions to it. As long as it works, it's the right answer. So that's, it gives you a freedom that's not available in education. That, um, alternate answer kind of thing, and also if you don't get it right in research, you're not given a B, or a C, or a D, or an F, or anything like that.

As Pamela notes, in research, failure and non-solutions are less of an impediment than in the classroom. Trying various solutions is instead encouraged in the research environment, which Mark notes aligns with how they naturally solve problems.

But, um... like, with having ADHD, at least within myself, like, I already try and figure out six different other things to [...] better understand the one thing. Or, like, I'm given one task, and I'm trying to figure out six different solutions to do that one task to, like, find the best one... as opposed to, like, the linear path, where it's like, 'okay, I've given this task... I know I can do it this way, so, like, let me accomplish it this way.' [...I]t's just not as fun that way.

In contrast to lectures, research allows students to work on unsolved problems and apply their creativity. In explaining how research helped them learn technical subjects, Julian appears to describe a process similar to how Van den Driessche et al. [27] classify exploration:

The stuff I'm doing is a lot more open-ended than what I'm used to doing in the circuits class [...] I think it helps a lot to be able to work through something really open-ended 'cause then you have to kinda search for some of the things that actually matter. That actually make[s] a difference, instead of just plugging everything into equations [...] In my case, it's helping a lot.

Participants routinely confirmed this principle; the exploratory process comes more easily to those with ADHD [26,27]; lectures do not. While labs offer some opportunities for hands-on learning, they often lack the open-endedness and genuine exploration found in research, as lab experiments typically have defined solutions and are designed for learning specific concepts rather than fostering true exploration. Daniel acknowledges that labs are more motivating than lectures: "I also really like the lab courses. They're my favorite, 'cause we actually get to do something, as opposed to like, sit around". As to why: "I would prefer to, like, break things in the lab, or like, do some cool fluids-related project and try and figure things out, as opposed to just [...] try to figure out the way that the professor wants me to do it" (Daniel). Lab components are a step in the right direction but fall short of the benefits of high-level research. Bridget illustrates the nuance when explaining what they like most about research over labs:

I guess, just kind of like, having my own stuff, and like, trying to work on something that hasn't actually been solved yet, and isn't just work for the sake of learning [...] I guess [it is] just fun to have my own computer, and they just tell me, like, I need you to do these things, and then I try and figure out how to do that in whatever way that I think I'm gonna be able to do it best.

In research settings, students can develop competence from the practical application of knowledge and experience success in solving complex problems. Additionally, research environments promote relatedness by encouraging collaboration and teamwork among students, faculty, and researchers, fostering a sense of community and support. This contrasts with the traditional lecture-based engineering education, which may not fully capitalize on the creative and exploratory strengths of students with ADHD. The collaborative nature of research projects allowed students with ADHD to engage with their peers and mentors, fostering a sense of camaraderie and support. This sense of relatedness contributed to their motivation and engagement in their work.

3.3. Theme 3: The Motivational Force of Solving Real-World Problems and the Importance of Tangibility

In the context of engineering education for students with ADHD, engaging in real-world problem solving and hands-on learning experiences not only satisfies these basic psychological needs but also enhances their engagement and motivation. Additionally, the nature of real-world problem solving presents open-ended, complex challenges that may be unpredictable and dynamic; real-world problems often present unexpected roadblocks that demand creative thinking and exploration in the pursuit of novel solutions [69]. Bridget described how real-world problems encountered in the research environment may require divergent thinking, while those encountered in an engineering classroom may not, saying, "[s]o, like there are multiple solutions to any problem. Well, any real-life problem. But like, in a classroom, there's probably one solution". By working on tangible projects that have a direct impact on real-world problems, students with ADHD can develop a sense of purpose and relevance while also leveraging their strengths in divergent thinking, which may both satisfy their need for autonomy and their natural tendency toward exploratory search and creative problem solving. Hands-on experiences allow them to develop competence through the practical application of knowledge and experience success in solving complex problems. Additionally, working on such projects often involves collaboration with peers and mentors, fostering a sense of relatedness and support. In this way, the motivational force of solving real-world problems and the importance of tangibility directly align with the principles of SDT, contributing to a more engaging and fulfilling learning experience for students with ADHD in engineering education.

Our analysis revealed that engaging in real-world problem solving and hands-on learning experiences emerged as significant factors in enhancing engagement and motivation for students with ADHD in engineering education. Participants expressed that the practical application of their knowledge in research settings fostered a sense of purpose and relevance, which they found more motivating than simply "learning for the sake of learning". For example, Julian says,

> *"...and so you don't have to, like, sit down and be quiet, and like, stuff like that, as much, so it's kind of, I think it'd be maybe more beneficial for students with ADHD in that sense, that it's like more, you don't have to like, sit there and like, listen to someone lecture you to learn. Like, it's more of a hands-on thing. It's more, like, you're directly involved, I guess."*

Moreover, hands-on learning experiences allowed students to develop a deeper understanding of the subject matter and facilitated their ability to apply their knowledge in various contexts. For example, Natasha described the excitement and adrenaline rush from the hands-on aspect of research and how it facilitated their learning. Specifically,

> *having to learn it so quickly, and that challenge, that adrenaline rush in learning, you know, all of that [...] It was hands-on. It was more interactive. It was easier to learn that way. [...] That's just the way that we learn, generally, as ADHD students, and when I went back to the classroom, [I wish] I could show that in a different medium.*

This hands-on aspect to research was a key factor in motivating students with ADHD to excel in their studies, as they could see the direct application of their skills and knowledge to the research questions of priority to the field, as outlined by the NAE's "Grand Challenges for Engineering" [70] and examples of which were given above.

Additionally, students with ADHD may benefit from hands-on activities in order to bridge the gap between abstract concepts and practical applications. In the research environment, participants found that working on tangible projects helped them to develop a deeper understanding of the material. Through hands-on experiences, students with ADHD were able to build their intuition, visualize complex concepts, and better comprehend the big picture, which they found particularly beneficial for their learning process. Tom highlighted the difference between solving problems in a classroom setting and working on real-world applications in research, emphasizing that the latter allowed for deeper understanding and faster learning:

> *Um, I've really enjoyed the chance to... to see, like, what hands-on actual problem-solving programming is, because in school, it's... it's here is a very isolated problem to solve. It... it can't do anything.You're just solving this problem to solve the problem. Um, here you're actually trying to get it to do something, and that's a huge step from what I've done in classes [...] I think it gives me a... an idea of what the end goal is [...] I know the foundation, and I know what is required, and what the idea is for, like, a real-world application... so I know sort of, the difference between the two and what's in between them [...] I guess that helped me learn it faster because I was able to spend more time on it.*

The participants also emphasized the importance of hands-on experiences in building their intuition and understanding of the big picture, which they found particularly beneficial for students with ADHD:

> *Even if I didn't necessarily remember everything, I'd still have an intuition for, oh well, I need this component and this component, because this component is gonna do this[...] In the actual experimental stuff, it's kinda almost more qualitative than quantitative[...] It's more getting the hands-on experience, like, knowing, if I change this component to a higher or lower value, what's that gonna do[...] Having the intuition makes it easier to apply that in other situations. (Bridget)*

This holistic approach to learning allows students with ADHD to tap into their innate curiosity and creativity, enabling them to explore multiple aspects of a project and make connections between different components. This multifaceted learning experience encourages them to think critically and holistically while synthesizing information. Another participant expressed their preference for engaging in all aspects of a project, emphasizing the value of experiencing the "moving parts" and the "whole package":

> *I like the experience of the moving parts, everything together, the whole package. I wouldn't like to just do the programming. Even in my classes, I like to participate in every aspect of it. Even though we'll work in groups most of the time, but I like to help on every part. I'll help with the programming, or help add things to the code, but I also like to do wiring, and move things around, and say, oh, well, I think this would be better here, or I think we should use this sensor instead. (Tom)*

These findings suggest that incorporating real-world problem solving and tangible, hands-on experiences in engineering education may be particularly engaging and motivating for students with ADHD, fostering a greater understanding of the material and the relevance of their learning to practical applications.

4. Discussion

The opportunity to expose undergraduate STEM students with ADHD to the research environment was inspired by the notion that ADHD fosters creativity, which is essential for high-level research performance. In addressing the research questions, our findings highlight the benefits of research experiences for students with ADHD, as well as the challenges they face in traditional engineering education settings. Our findings support the idea that students with ADHD indeed thrive in the research environment, where open-ended problems encourage divergent thinking, and novelty is valued over rote memorization. This reinforces the growing argument within engineering education that a paradigm shift is necessary for the field to meet modern needs [7,10,25,29,34] and suggests that students with ADHD benefit greatly from learning within the research environment. These findings have implications not only for the students themselves but also for researchers and STEM education more broadly.

The benefits of this approach are wide ranging, impacting students, researchers, and the field at large. For students, a blended approach of expanded research opportunities and accommodations when necessary may be more ethical, considering the stress, anxiety, and lack of drive participants experienced in traditional engineering education. Researchers who bring students with ADHD into their labs may gain a highly motivated, innovative researcher whose strengths lie in developing and testing novel solutions to real-world questions. Finally, incorporating research opportunities for neurodiverse students in engineering education offers two main benefits for the field at large: retaining neurodiverse talent and facilitating a natural pathway for graduate study. By revising curricula to nurture the strengths of students with ADHD, we can ensure their valuable contributions to the field, aligning with the National Academy of Engineering's call for rapid innovation [4].

To fully benefit from these students' strengths, we as engineering educators must address the disparity between undergraduate and graduate engineering education values, with the former emphasizing standards and procedures and the latter promoting innovative thinking. Undergraduate students learn the standards and procedures to arrive at the "right" solution; innovation is generally not encouraged in the classroom environment [71,72]. Still, students are expected to become independent and innovative thinkers should they pursue advanced degrees. Early research exposure can bridge this gap, helping students develop as innovative thinkers and creating a seamless transition to graduate studies [7,25,29,73]. The success of the REU Site, where several participants pursued advanced degrees, supports this claim. Of the 29 total REU participants, 43% pursued graduate degrees in engineering (26% Ph.D. and 17% MS), including one who received a prestigious, nationally recognized fellowship to fund their graduate studies.

However, it is important to acknowledge the challenges faced by students with ADHD in traditional engineering education settings. They often experience acute stress and feelings of inadequacy, which can lead them to consider leaving engineering and/or higher education altogether. We only know of the stories and pain of those who attended this program. For many, this summer program was their last possible chance, and it turned out to be a positive, transformative experience.

Alternative explanations for the observed improvements in engagement and motivation among students with ADHD in the research environment can include factors such as improved social support and personalized learning experiences. The sense of community built within the program played a critical role in enhancing students' experiences. Through roundtable discussions, seminars, and social events, students were able to share their challenges and connect with peers who had similar struggles, leading to the realization that their difficulties were not unique to them, but rather a result of biases within the traditional education system. This helped to shift their self-perception and view their ADHD as a strength rather than a weakness.

Building a sense of community, coupled with specialized seminars featuring high-profile speakers, empowered students by validating their experiences and highlighting the benefits of their unique cognitive styles, such as creativity, divergent thinking, and risk taking in problem solving. The personalized learning experiences offered within the research environment catered to the individual needs of students with ADHD, allowing them to thrive academically and personally. This supportive environment, which valued their strengths and addressed their challenges, contributed to the observed improvements in engagement, motivation, and self-image. By considering these alternative explanations, it is evident that a combination of factors, including social support, personalized learning experiences, and a sense of community, played a significant role in enhancing the educational experiences of students with ADHD in the research environment.

The findings from this research suggest several key features that may support the success of students with ADHD within the research environment. Researchers and programs wishing to provide an environment in which students with ADHD may thrive may wish to consider (a) cultivating a shared understanding that students with ADHD have the potential to make a unique contribution to the field, (b) integrating a strength-based approach to neurodiversity (i.e., emphasis on student assets, use of affirming language), (c) leadership and input from neurodiverse faculty and program staff, (d) structured activities that foster connections among students with ADHD to reduce isolation, increase social support, and enhance a sense of belonging, (e) open-ended research tasks that encourage creative problem solving in areas of interest to students, and (f) a flexible work schedule.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, the small sample size of 10 students (with 8 completing this study) provides an exploration of the experiences and perspectives of a small group of students; however, these experiences may not represent the broader population of students with ADHD in STEM fields. Additionally, participants were selected from an NSF-funded REU Site specifically designed for students with ADHD, which may introduce a selection bias, as the students who participated in the program could be more motivated and engaged than the general population of students with ADHD. Furthermore, the use of IPA as a qualitative method relies on the interpretation of participant experiences by the researcher, which can lead to potential biases and subjectivity in the analysis and interpretation of the data.

This study did not include a control group of students without ADHD, making it difficult to determine if the benefits and challenges identified in this study are unique to students with ADHD or if they apply more broadly to all students in STEM fields. The generalizability of the findings may also be limited by the fact that all participants were part of an REU Site, and their experiences and perspectives may not be representative of all students with ADHD in engineering or other STEM fields who have not participated in similar programs. Finally, the participants in this study were individuals who chose to attend the REU Site, which may indicate a pre-existing affinity for research or a higher level of motivation to engage in this type of learning experience. This could potentially bias the results, as their experiences and perspectives may not be representative of all students with ADHD in engineering education.

Looking forward, future research should focus on discerning whether students with ADHD disproportionately reap the benefits of this Site compared to neurotypical students, and if so, why. Future work may also evaluate the hypothesis that students with ADHD, who often exhibit traits such as an inclination toward risk taking and higher divergent thinking skills, perform differently in research settings, utilizing the strengths-based approach to neuro-inclusivity. By identifying and grappling with these individual traits, we may better understand how these elements interact within the context of scientific research and how they might contribute to the success of students in such environments. Additional research should also assess the sense of belonging in students with ADHD, interpreting their perceptions of how well they integrate and participate within the unique learning environment of summer undergraduate research. As social elements often play a vital role in the effectiveness of student participation and learning, understanding the factors that contribute to their sense of belonging could develop more inclusive and effective educational settings. Finally, these findings can help identify gaps in the current educational approaches that limit the level and quality of genuine research experiences for students in the engineering curriculum. By leveraging these insights, we can tailor our teaching methods and curricula to aid instructors in their effort to cultivate more inclusive and advantageous learning experiences for all students.

5. Conclusions

Our project evaluates the outcomes of an experimental REU Site that brought engineering students with ADHD to an R1 university to engage in high-level research. This Site was inspired by findings that link ADHD with enhanced creativity, upon which our case study supports and expands. We also find support for related theories of ADHD cognition, with students expressing a preference for exploration over exploitation and an increased ability to filter a wide variety of data to find novel solutions. We contend that the research environment provides crucial motivating factors for students with ADHD, as it aligns with their strengths, as hypothesized by these clinical studies. Our core findings encompass research engaging the explorative mindset, research projects creating stakes and a sense of accomplishment, and the lab space providing crucial tangibility as opposed to the abstractions of traditional educational modes.

These findings support the strength-based model and the principles of Self-Determination Theory, which emphasize focusing on the strengths of individuals with ADHD and satisfying their needs for autonomy, competence, and relatedness. A model that starts from their strengths as creative individuals, and places them in an environment that capitalizes on that process, appears to enable them to learn faster than with conventional lecture models. We suggest that modifying traditional STEM curricula to include opportunities for undergraduate research presents numerous benefits across the engineering enterprise. Such modifications could boost retention among non-traditional learners and encourage them to pursue advanced degrees.

However, implementing this paradigm shift would require a significant investment of time and resources to reorient entire departments or engineering schools. Nevertheless, successful models of this shift within departments that embrace neuro-inclusivity do exist. Two strong examples of embracing neurodiversity and the strength-based approach are the INCLUDE Project at the University of Connecticut's Department of Civil and Environmental Engineering [74] and Vanderbilt's Frist Center for Autism and Innovation [75]. If the potential benefits are not compelling enough to prompt change, the common harms experienced by students with ADHD in traditional settings should be considered. Refusing to allow students to learn in an environment that aligns with their strengths and satisfies their basic psychological needs, as posited by SDT, is an ethical failure, causing talented, creative students to suffer needlessly and depriving the wider STEM community of innovation at a time when innovation is crucial to address the modern world's existential challenges.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: Data from this study are available upon request to the corresponding author. The data are not publicly available for the privacy of participants.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Interview Question Bank

1. Creativity
2. How would you describe yourself as a person?
3. Can you tell me about some of the ways that you are creative?
4. Can you describe some of the challenges you face with your creativity?
5. Do you ever find it hard to come up with ideas?
6. Do you ever find it hard to follow through on your ideas?

7. Experiences in engineering
8. Tell me the story of how you came to focus on engineering?
9. If you were not doing engineering, what other major(s) would you consider pursuing?
10. Do you think your undergraduate engineering education has nurtured your creativity?
11. Have you ever suppressed your creative thinking for the sake of a better grade or educational outcome?
12. Challenges with instructions
13. Could you tell me how you have been able to use your creativity in your engineering program? are there any research projects that you have been able to be more creative on (what specifically did you do for that?)? Is there any homework that you have been able to be more creative on (what specifically did you do for that?)? Has there been any specific coursework that you have been able to be more creative on (what specifically did you do for that)?
14. Could you describe some of the challenges you have faced in your engineering program?
15. Do you ever have trouble misunderstanding or misinterpreting instructions?
16. Faculty advisor
17. Classroom
18. Work teams
19. Can you tell me about a time when you misinterpreted the instructions that were presented to you?
20. Why do you think that happened?
21. Is that typically the case when you have trouble with instructions, or are different types due to other factors that you can think of?
22. Do you think, or how do you think, that can be avoided?
23. Writing instructions down as they are said
24. Reading instructions instead of hearing them
25. Aside from specific strategies, are there situations where you are more likely to understand instructions fully?
26. Certain people
27. More or less people present
28. Certain types of tasks

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